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## Summary

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Improvements in electronic device technology can occur through incremental changes and improvements in current and existing technologies or by the introduction of new techniques. This research program has developed a new techniques for manufacturing nanoscale silicon compatible devices in a single step fabrication process leaping beyond existing technologies. Using chemical vapor techniques in combination with carefully designed source molecules, it has now become possible to fabricate thin materials by selective area processing - the "direct writing" of material. Our general approach to device fabrication requires the use of novel source molecules for chemical vapor deposition (CVD). Synchrotron (X-ray) radiation has been employed to selectively deposit each active layer of a semiconductor device in a single step process. There is the potential that each step in fabricating a diode or thin film transistor can deposit material with submicron feature resolution. These processes are a form of projection lithography which requires far fewer steps than conventional lithography and can be employed to fabricate devices from novel semiconductors with abrupt, well characterized interfaces.

The development of this technology has attracted the attention of two industrial laboratories who will provide additional support and collaborative assistance in the future. The goal of this collaborative research effort and of our industrial partners is to develop semiconductor device fabrication techniques that will result in technologies easily added to the fabrication of conventional as well as new semiconductor devices.

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Drift Mobility Measurements in Thin Film Boron Carbide

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## Summary

Improvements in electronic device technology can occur through incremental changes and improvements in current and existing technologies or by the introduction of new techniques. This research program has developed a new techniques for manufacturing nanoscale silicon compatible devices in a single step fabrication process leaping beyond existing technologies. Using chemical vapor techniques in combination with carefully designed source molecules, it has now become possible to fabricate thin materials by selective area processing - the "direct writing" of material. Our general approach to device fabrication requires the use of novel source molecules for chemical vapor deposition (CVD). Synchrotron (X-ray) radiation has been employed to selectively deposit each active layer of a semiconductor device in a single step process. There is the potential that each step in fabricating a diode or thin film transistor can deposit material with submicron feature resolution. These processes are a form of projection lithography which requires far fewer steps than conventional lithography and can be employed to fabricate devices from novel semiconductors with abrupt, well characterized interfaces.

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### **A. Synchrotron Radiation CVD (Projection Lithography)**

The photons in synchrotron radiation have more than enough energy to initiate decomposition in CVD source molecules or chemical reactions at solid surfaces. Core level excitations lead to hole localization in the bonding orbital of the molecule [1]. This hole localization results in the photolysis of molecules as well as dissociation into multiply charged single ions and photo simulated desorption (PSD) of adsorbates from semiconductor surfaces. In addition, secondary electrons generated by the high energy photons from the substrate can initiate decomposition [1-7] of adsorbed molecules. The easy access of bright collimated broad band radiation for exploratory materials research, and of the short wavelength radiation which allows for smaller feature resolution (for selective area deposition), has led to synchrotron radiation being successfully employed in chemical vapor deposition particularly by Japanese research groups [8-10] and our own group [2-5, 11-13]. Furthermore, the tunability of energy available from synchrotron radiation through the use of insertion devices or monochromators may someday provide some means of controlling the reaction pathways.

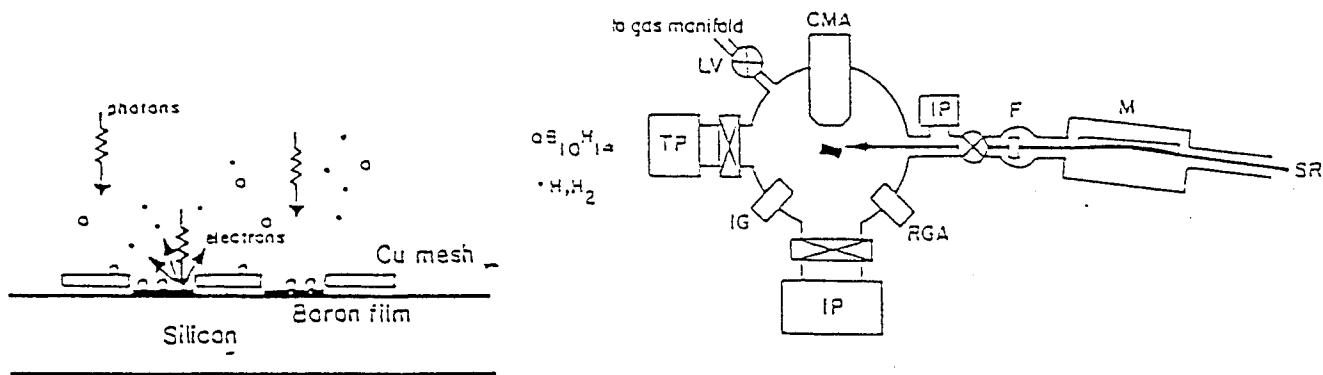


Figure 1: Schematic of SR CVD apparatus (at the right) and a schematic representation of the dissociation process (at left). The synchrotron radiation (SR) is focused by a mirror into the experimental chamber, separated from the beam line by differential pumping (IP). A filter (F) can be inserted into the synchrotron radiation to block or filter the light. The main chamber is pumped by an ion pump (IP) and turbo-molecular pump (TP). The system is equipped with a quadrupole mass spectrometer (RGA) for photostimulated desorption studies and residual gas analysis, a cylindrical mirror analyzer (CMA) for Auger electron spectroscopy (AES), an ion bombardment of the surface, and a leak valve (LV) for controlling source gas flow into the vacuum system.

## B. ACCOMPLISHMENTS

The highlights of our work to date are the fabrication of the first diode fabricated by direct writing using synchrotron radiation [5]. This diode is of comparable quality to a diode fabricated by more conventional techniques as seen in Figure 2. The SR-CVD technique clearly can work as a fabrication methodology.

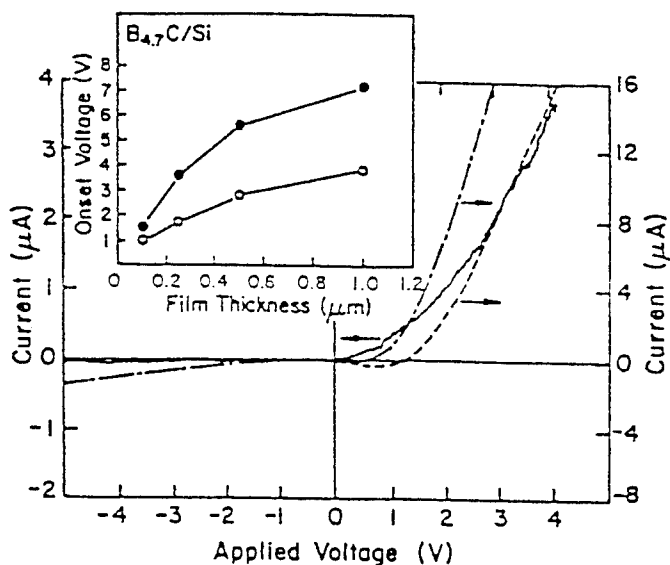
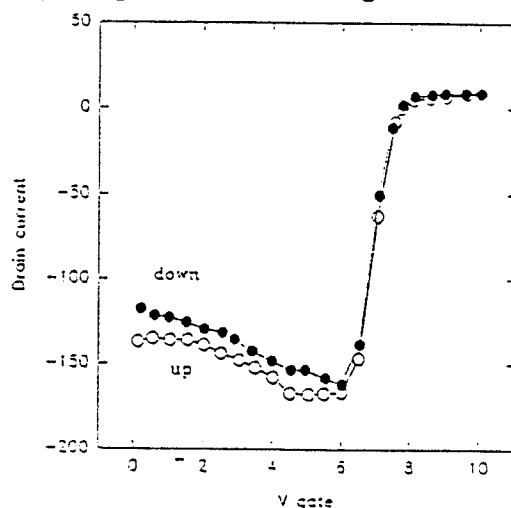


Figure 2 The I-V curves for synchrotron radiation assisted CVD fabricated boron carbide-silicon heterojunction diodes identified by the solid line (—) and plasma enhanced CVD fabricated diodes identified by the dashed line (---), and with illumination, identified by the dot-dashed line (-.-.-). The insert shows the onset voltage for the  $B_{4.7}C$  on Si(111) heterojunction diode fabricated by PECVD, as a function of boron-carbide film thickness. Taken from reference [5].

A great deal of our effort to date has been with a rather novel materials system. Complicated devices are possible with these materials as is indicated in Figure 3. We have succeeded in the fabrication of a depletion mode field effect transistor. The techniques and chemistry necessary to make such complex devices should be readily applied and utilized in SR-CVD and e-beam initiated CVD without difficulty.

It is important to note that the approach outlined here will lead to high resolution device fabrication with resolution potentially exceeding anything employed in device manufacturing to date. This is a fundamentally new technology compatible with existing silicon technologies and

Figure 3. The current versus bias voltage curve for a B<sub>5</sub>C/Boron/Si(111) depletion mode transistor. Hysteresis of the curve can be seen to be minimal while the gain is quite high.



it has been demonstrated to work. Japan and Korea are investing in developing this technology, but apart from this collaborative effort, there is little comparable success demonstrated by research groups in North America. We are, after all, the only research group, as yet, to have made a working semiconductor device by direct writing using synchrotron light.

The ultimate resolution of this technique has not been reached, nor has any effort been made to reach that ultimate resolution, but it should be certainly well below 1000 Å. The test of whether such resolution is feasible is really a test of whether working devices can be fabricated on that size scale. Clearly we believe this is possible.

The fabrication of transistors should now make it possible for us to measure the mobility of these rhombohedral boron based materials. At present, we are clearly behind schedule in reaching this essential goal. We have only just begun to make transistors with any sort of fabrication reliability and have just demonstrated that the majority carriers are electrons. The lack of progress in the major task of this research program is a reflection of how little we do know about this material. We are succeeding in overcoming the hurdles that stand in the way of this task and we believe that further results addressing this issue will be forthcoming.

We have also been concerned about packaging problems, and have proposed to investigate this issue within the scope of our continued AFOSR funding. In addressing the general area of packaging, we have developed a technique for "drawing" wires using a scanning

tunneling microscope or STM [14]. These wires are now the smallest wires yet made (only a few hundred Ångstroms across). This is the most successful application of this technique (STM-CVD). The results are clearly shown in Figures 4 and 5.

Figure 4. A palladium ring deposited on the surface. The ring has an outer diameter of 220 nm, a thickness of 50 nm and is 6 nm high. The ring of palladium metal was fabricated from a palladium containing organometallic source compound [14].

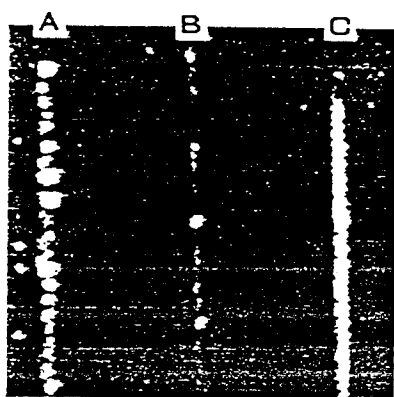
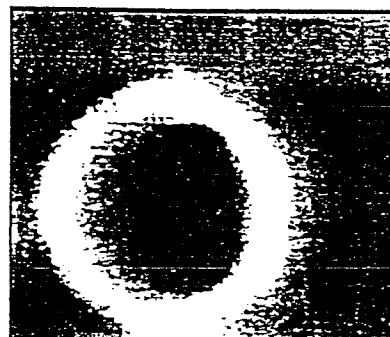


Figure 5. Three lines of palladium deposited using an STM on a surface. The lines are about 50 nm wide and the tallest feature is 10 nm high.

The last, but perhaps most important issue that has come out of this past year, is that we have now developed an organometallic complex that we believe will result in semiconductor grade rhombohedral boron-phosphide. This development is important, because, it only with the addition of phosphorus to the alloy, can the band gap be increased beyond 2 eV.

Published:

Sunwoo Lee and P.A. Dowben, "The properties of Boron Carbide/Silicon Heterojunction Diodes Fabricated by Plasma Enhanced Chemical Vapor Deposition", Appl. Phys. A58, 223 (1994)

D. Byun, S.-D. Hwang, P.A. Dowben, F.K. Perkins, F. Filips and N.J. Ianno, "Heterojunction Fabrication by Selective Area Chemical Vapor Deposition Induced by Synchrotron Radiation", Appl. Phys. Lett. 64, 1968 (1994)

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Submitted:

Dongjin Byun, Seong-don Hwang, J. Zhang, H. Zeng, F.K. Perkins, G. Vidali and P.A. Dowben, "Synchrotron Radiation Induced Decomposition of Closo-1,2-dicarbadoodecaborane", Journal of Vacuum Science and Technology

In addition, the current AFOSR contract has substantially contributed to the education of two students. John Kushneir is currently writing up his M.Sc. in Physics on the basis of a thesis funded by AFOSR and an industrial partner: Leybold-Inficon. Mr. Dongjin Byun is expected to begin writing his Ph.D. thesis in engineering based upon work funded by AFOSR.

We have established collaborations with two industrial partners: Leybold-Inficon (located in Syracuse, New York) and International Business Machines (with the Laboratories in Endicott, New York). These companies have expressed interest in our efforts and we hope that they will assist us in transfer of our results and technology to industry. The University of Nebraska has obtained permission from the board of regents to pursue further patents related to our work over the past year. It is my understanding that the University is moving ahead on obtaining permission from AFOSR to obtain a patent and will go ahead in filing for a patent. We have also worked in concert and collaboration with the Naval Research Laboratory (staff member F.K. Perkins).

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